DER-CAM & SEDS

Optimizing Building Energy Use: A Systemic Approach

by

Chris Marnay & Michael Stadler

C_Marnay@lbl.gov & MStadler@lbl.gov - +1.510.486.7028 - http://der.lbl.gov

other team members: Hirohisa Aki, Inês Lima Azevedo, Sam Borgeson, Brian Coffey, Ryoichi Komiyama, Kristina LaCommare, Judy Lai, & Afzal Siddiqui

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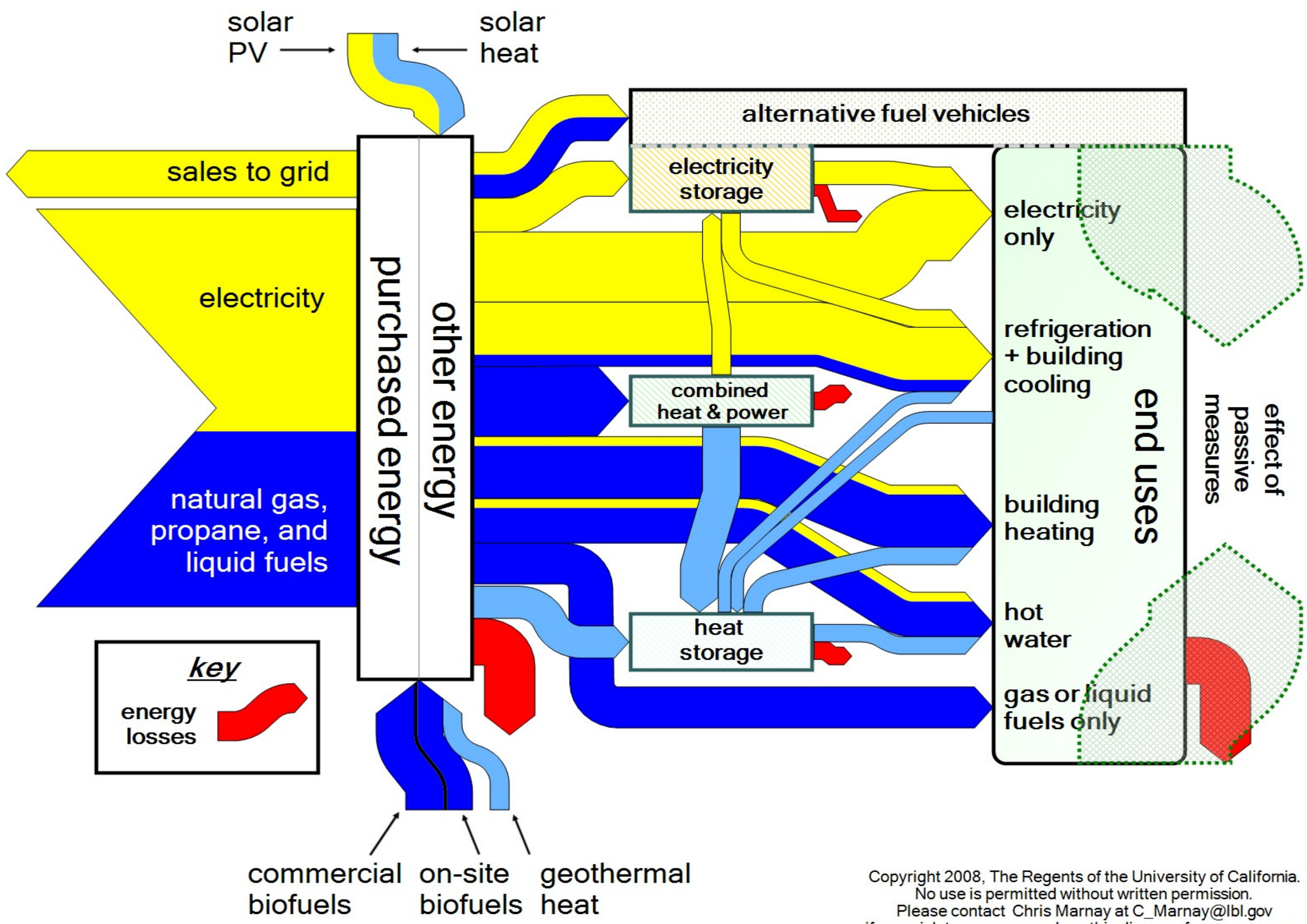
Outline

- systemic analysis of building energy systems
- executive summary
- Distributed Energy Resources Customer Adoption Model (DER-CAM)
- Stochastic Energy Deployment System (SEDS)
- conclusions and future work

Global Concept



Exec. Summary

systemic approach applied in two distinct models:

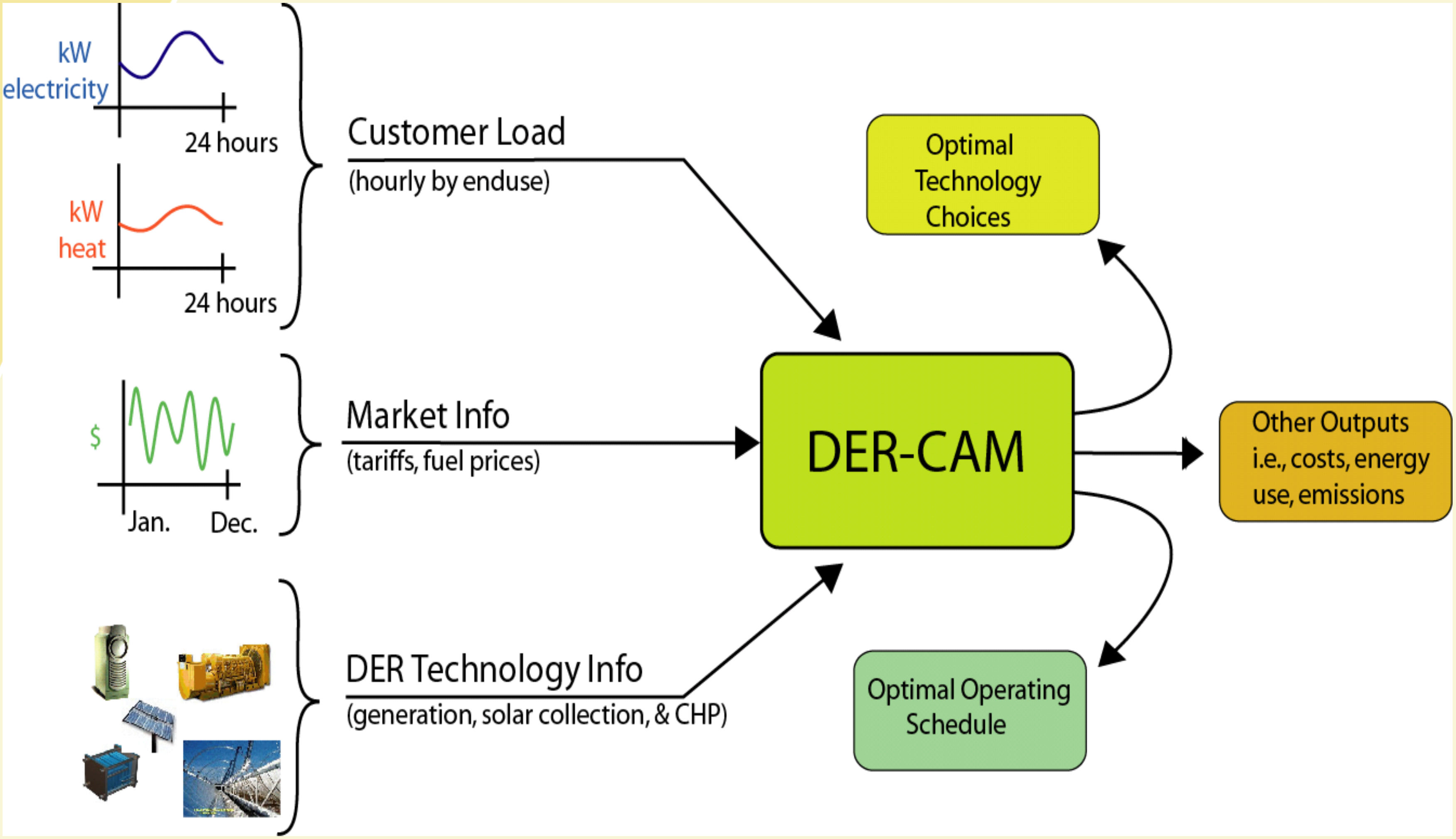
Distributed Energy Resources Customer Adoption Model

- given hourly end-use requirements, DER-CAM produces pure technology neutral optimal results and schedules
- can find optimal installation & use of storage
- reveals cost-carbon abatement trade-off curve and optimal ZNEB solutions
- requires extension into demand-side, financials, etc.

Stochastic Energy Deployment System

- Berkeley Lab has built the SEDS Lite Buildings Module
- and can conduct rudimentary analyses of PV and SSL

DER-CAM Logic



What is DER-CAM?

- Mixed Integer Linear Program (MILP), written in the General Algebraic Modeling System (GAMS®)
- minimizes annual energy costs (or carbon emissions or multiple objectives) of providing services on a microgrid level (typically buildings with 250-2000 kW peak)
- produces technology neutral pure optimal results with highly variable run times
- used for more than 5 years by Berkeley Lab and under license by researchers in the US, Germany, Spain, Belgium, Japan, and Australia
- potentially commercialized

Biz Case Project

- find value of electrical+heat storage paired with CERTS Microgrid (CM) power quality and reliability (PQR)
- inverter-based variable speed internal combustion engine genset (CM-100) with CM, surge (125 kW), and CHP
- designated sensitive load supplied during grid disturbance
- 6 example buildings: paired CA & NY nursing homes, schools, and data centers

Available Equipment

discrete

	CM-100	fuel cell
capacity (kW)	100	200
sprint capacity	125	
installed costs ($/kW)	2400	5005
with heat recovery ($/kW)	3000	5200
variable maintenance ($/kWh)	0.02	0.029
efficiency (%, HHV)	26	35
lifetime (a)	20	10

only integer installations

continuous

fixed unavoidable costs

	electrical storage (lead acid)	thermal storage	flow battery	absorption chiller	solar thermal	PV
intercept costs ($)	295	10000	0	20000	1000	1000
capacity ($/kW or $/kWh)	193	100	2125/ 220	127	500	6675
lifetime (a)	5	17	10	15	15	20

Tecogen 100+ kW Gensets

NY Nursing Home Rslts.

at current technology costs

	A	B	C	D	E
	do-nothing	*invest* in all technologies	low storage costs and PV costs and PV incentive of 2.5$/W	force low storage / PV and solar thermal results	low storage and PV costs (PV incentive 60%)
equipment					
CM-100 with HX (kW)		0	0	0	0
abs. chiller (kW in terms of electricity)		100	112	112	112
solar thermal collector (kW)		1438	2350	2350	2350
PV (kW)		0	0	0	0
electric storage (kWh)		0	294	n/a	294
thermal storage (kWh)	n/a	0	4862	n/a	4862
annual costs (k$)					
Total	1195.5	1161.27	1148.6	1178.56	1148.6
% savings compared to do nothing	n/a	2.86	3.92	1.42	3.92
annual energy consumption (GWh)					
electricity	6.02	5.9	5.95	5.82	5.95
NG	7.14	5.24	3.5	4.82	3.5
annual carbon emissions (t/a)					
emissions	1555.23	1439.26	1361.49	1402.2	1361.49
% savings compared to do nothing	n/a	7.46	12.46	9.84	12.46

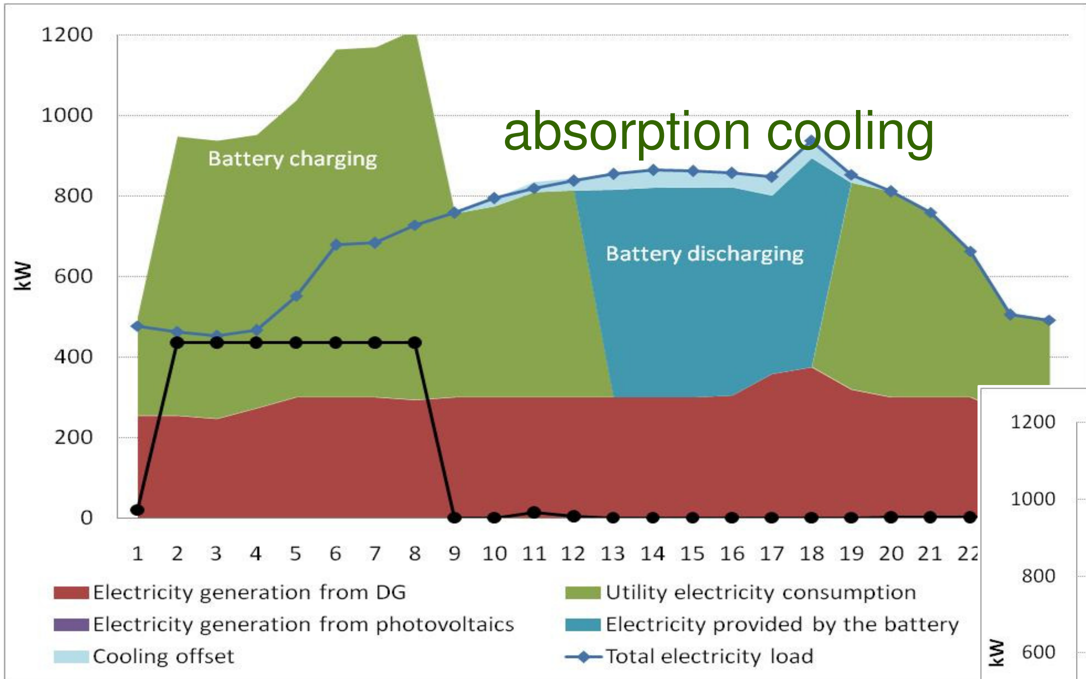
marginal carbon emission rate ConEd: 200g/kWh

ICE and PV is not an option

11 times bigger than in CA!

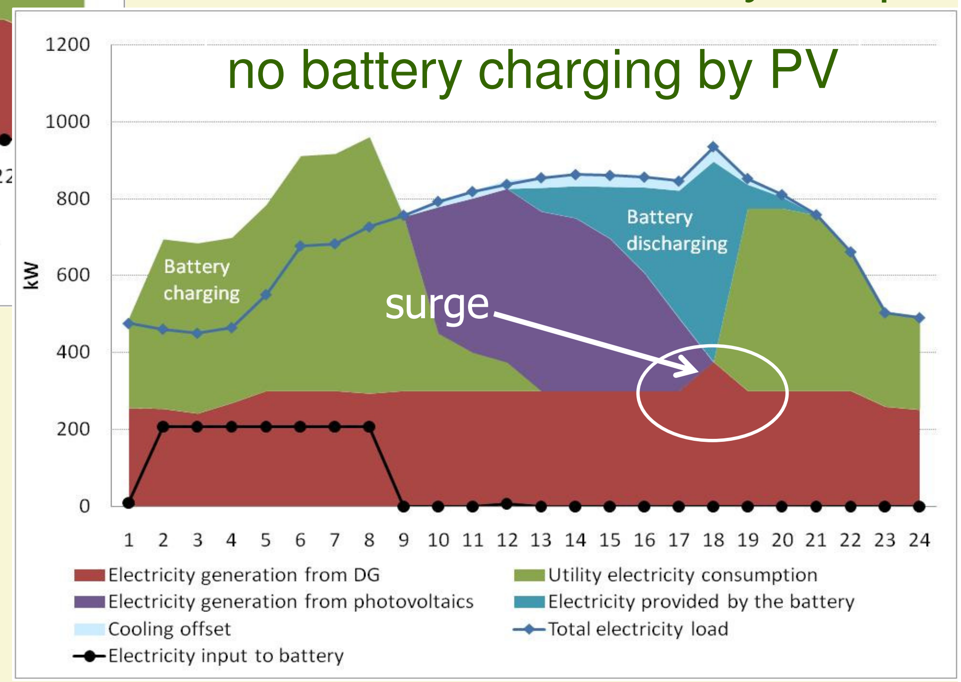
storage adoption is inverse to the CA

CA Nursing Home Rslts.



Case C: July Weekday Diurnal Electricity Shape

Case E: July Weekday Diurnal Electricity Shape



Biz Case Storage I

- NY nursing home and school with flat electricity tariffs and higher natural gas prices show
  - less electric storage and ICE adoption
  - but more solar thermal adoption despite less solar insolation
  - → tariff is most influential factor (TOU and demand charges in CA versus almost flat tariffs in NY)
- storage inefficiencies and constant marginal emissions cause higher carbon emissions
- problem worse if coal is marginal off-peak, e.g. SoCal school

Biz Case Storage II

- storage technologies not attractive at current price levels
- applying lower storage costs, the CA examples show electricity storage adoption driven by on-peak purchase avoidance
- storage systems are charged by cheap off-peak electricity i.e. they compete with PV
- PV is not an *economic* option to charge electric storage, even at price levels 60% lower than today's prices

PQR Effect

- CM power quality and reliability (PQR) adds customer value but its valuation is uncertain (visceral?)
- PQR value of technologies varies
  - CM-100's have high known availability
  - PV is intermittent
  - batteries might not be fully charged
  - lead-acid batteries can only be discharged to 30%
  - etc., …
- 6 example buildings: paired nursing homes, schools, and data centers in CA & NY
  - assumed added cost of 25 $/kW and switch, 100 $/kW
  - found value of PQR that balances with *invest* case

Sensitive Load Contrib.

technology	contributes	probability
CM-100	yes	0.90
fuel cell	yes	0.90
electricity storage	yes	0.15 to 0.21 (southern CA school)
heat storage	no	n/a
flow battery	yes	1.0
abs. chiller	no	n/a
PV	yes	0.18 (NY examples) to 0.22 (southern CA School)
solar thermal	no	n/a

PQR Results I

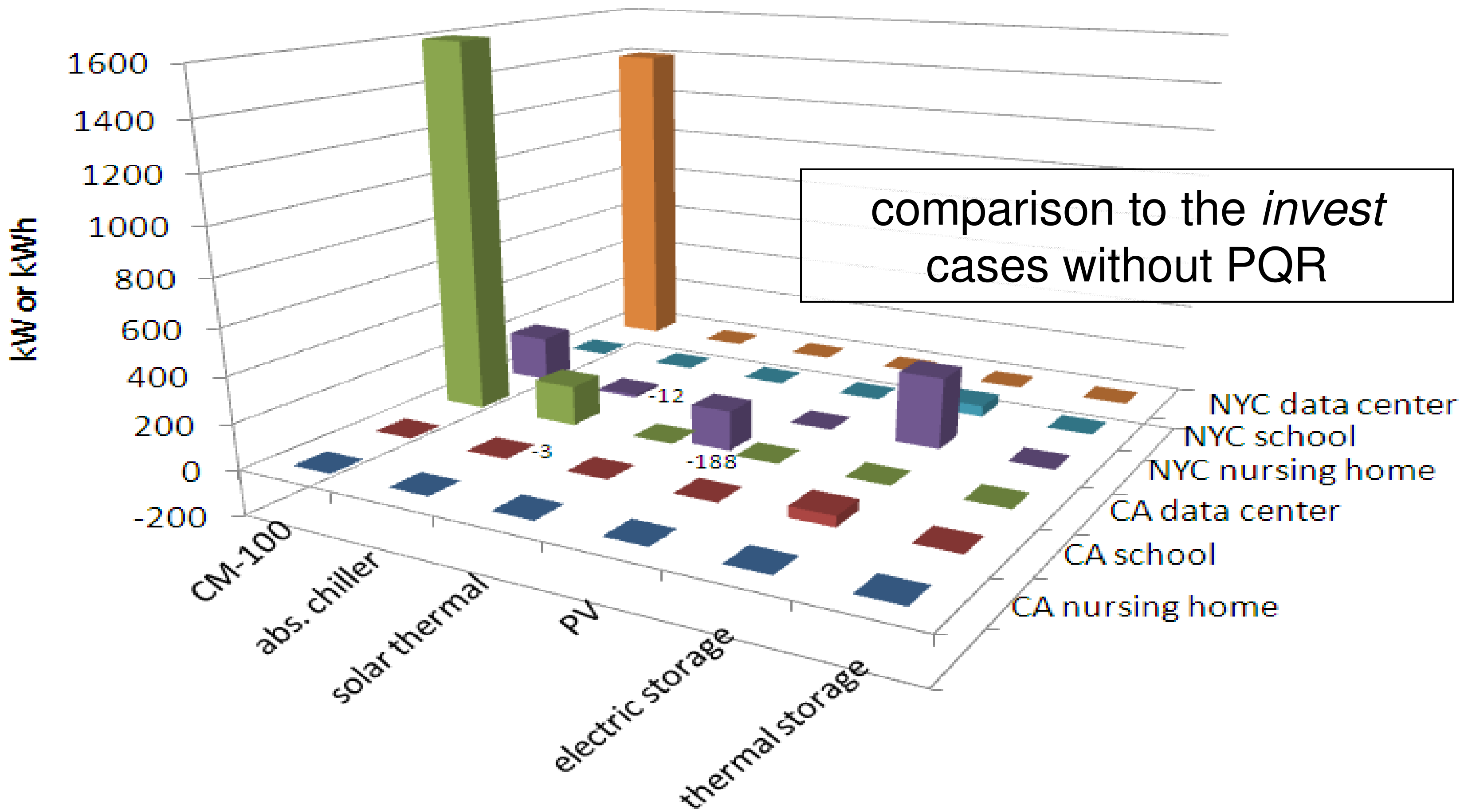
sensitive load

		benefit ($/kW)	base (%)	peak (%)
CA	nursing home	<25	50	10
	school	<25	25	0
	data center	125	100	100
NY	nursing home	<25	50	10
	school	<25	25	0
	data center	200	100	100

adoption compared to the *invest* cases

change	CA nursing home	CA school	CA data center	NYC nursing home	NYC school	NYC data center
CM-100 (kW)	0	0	1600	200	0	1400
abs. chiller (kW)	0	-3	175	-12	0	0
solar thermal (kW)	0	0	0	-188	0	0
PV (kW)	0	0	0	0	0	0
electric storage (kWh)	0	47	0	311	48	0
thermal storage (kWh)	0	0	0	0	0	0

PQR Results II



comparison to the *invest* cases without PQR

Demand-Side Measures

demand measures are characterized by the:

- costs of reducing 1 kW of load ($/kW)
- max. potential of **load** reduction (%), and
- annual time limit (h of behavioral change or technical limit)

Electricity	VariableCost ($/kW)	MaxContribution (%)	MaxHours (hours)
low	0.00	30	4380
mid	0.06	10	8760
high	1.00	5	760

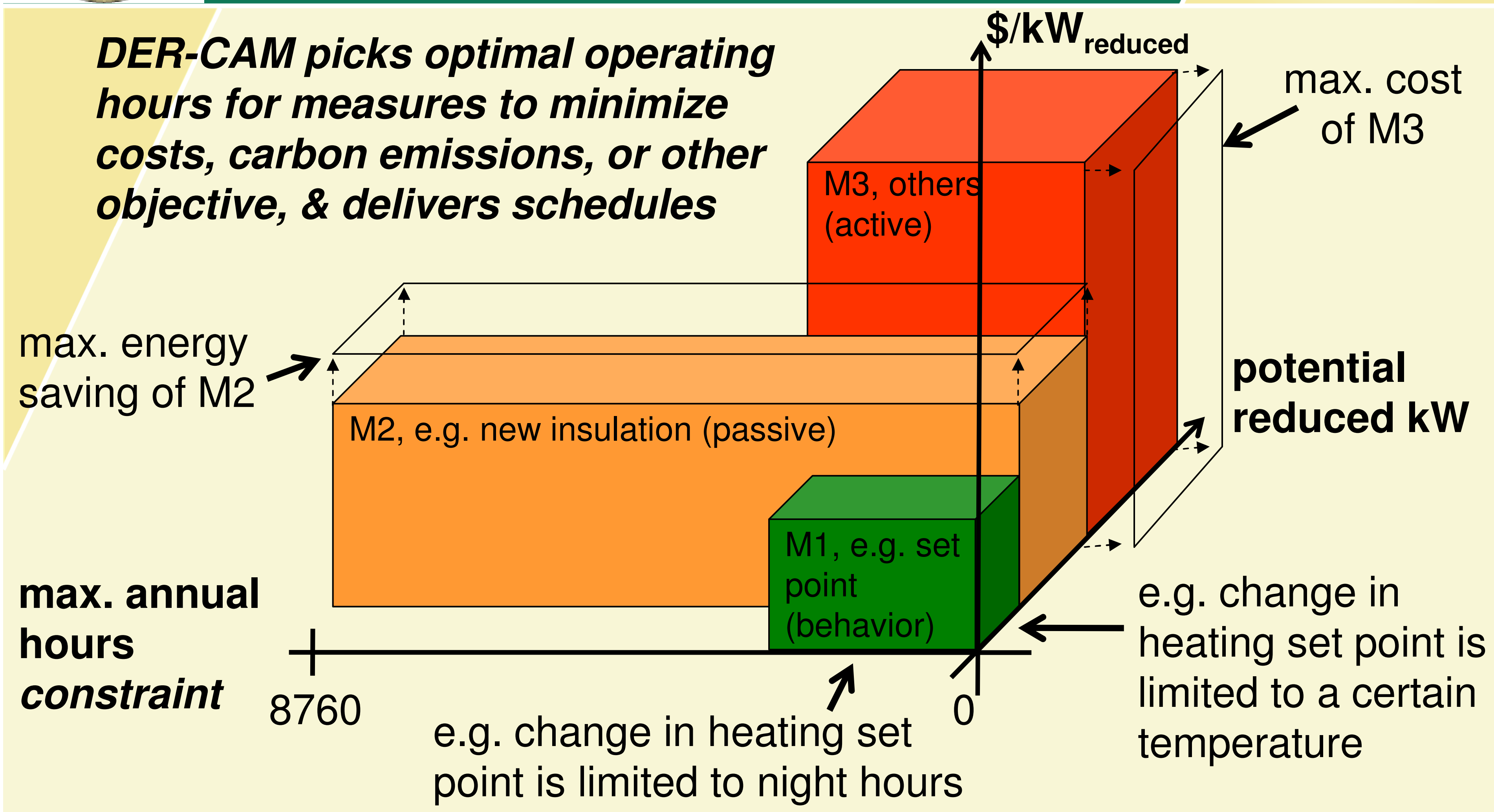
assumed data used here
→ refinement possible

heating measure costs for “mid” are assumed to be slightly less than, and for “high” slightly higher than, PG&E NG costs

Heating	VariableCost ($/kW)	MaxContribution (%)	MaxHours (h)
low	0.00	30	1095
mid	0.03	20	8760
high	0.05	10	8760

Dmd. Measure Potential

DER-CAM picks optimal operating hours for measures to minimize costs, carbon emissions, or other objective, & delivers schedules



Model

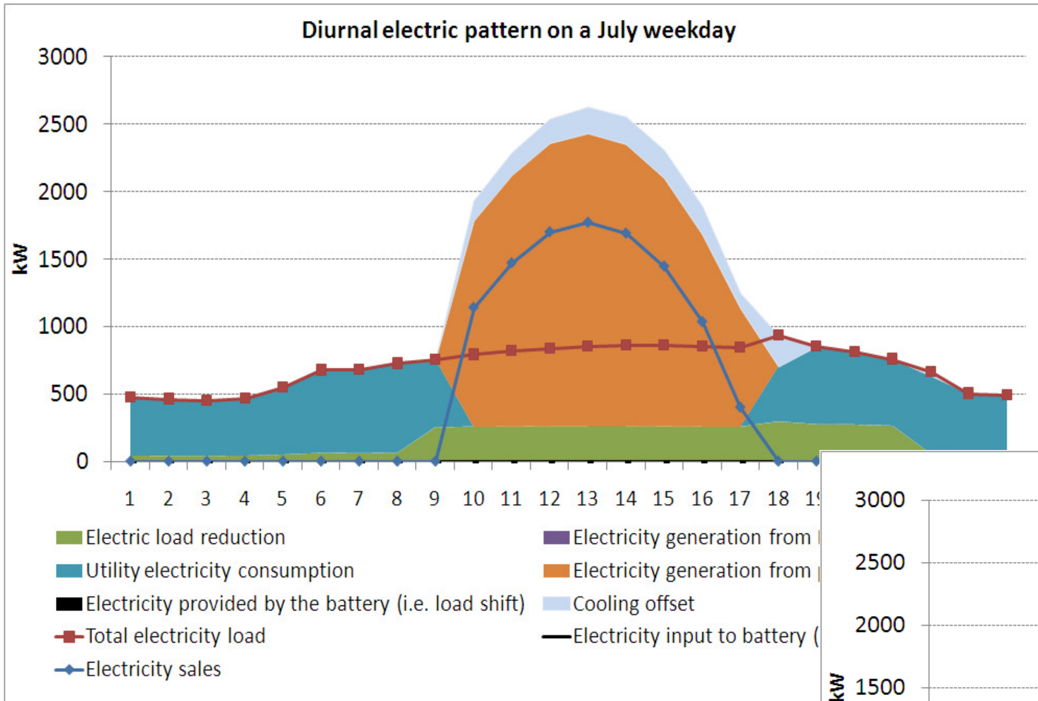
Zero Net Energy Bldgs.

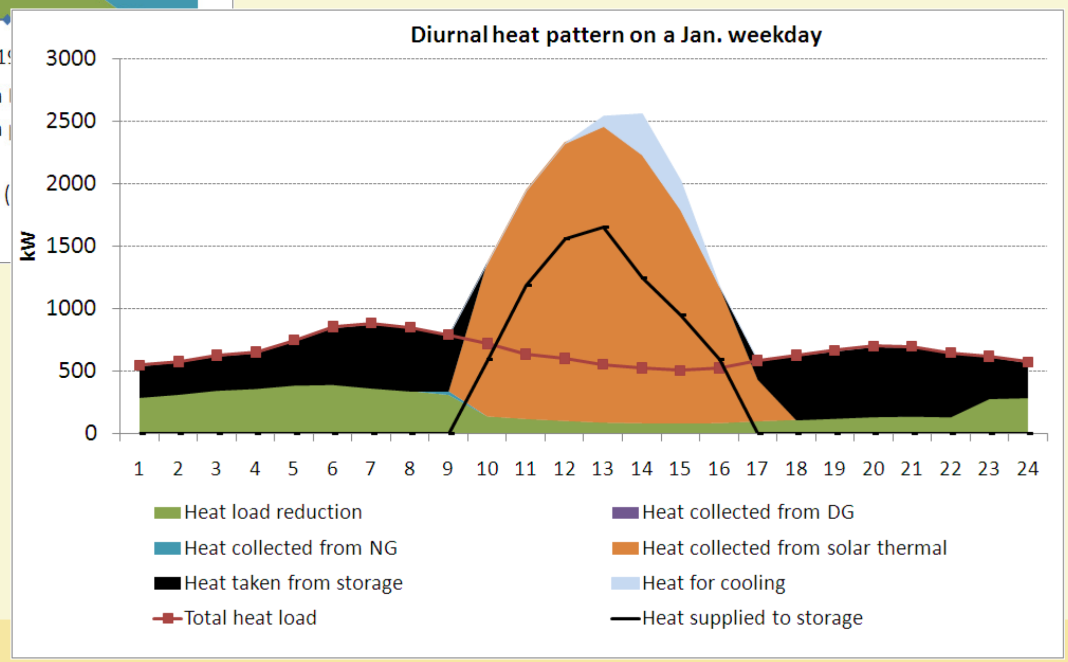
- ZNEB constraint: purchased energy = sold energy
- energy must be in common units (heat equivalent)
- footprint constraint: the possible space for PV and solar thermal adoption must be restricted
- multiple possible minimization objectives:
  - total energy bill
  - carbon emissions
  - combination, or other …
- consideration of demand response measures:
  - load <u>shifting</u> measures represented by storage, and
  - load <u>reduction</u> measures represented by abstract “low”, “mid”, and “high” measures for electricity-only and heating loads.

CA Nursing Home Equip.

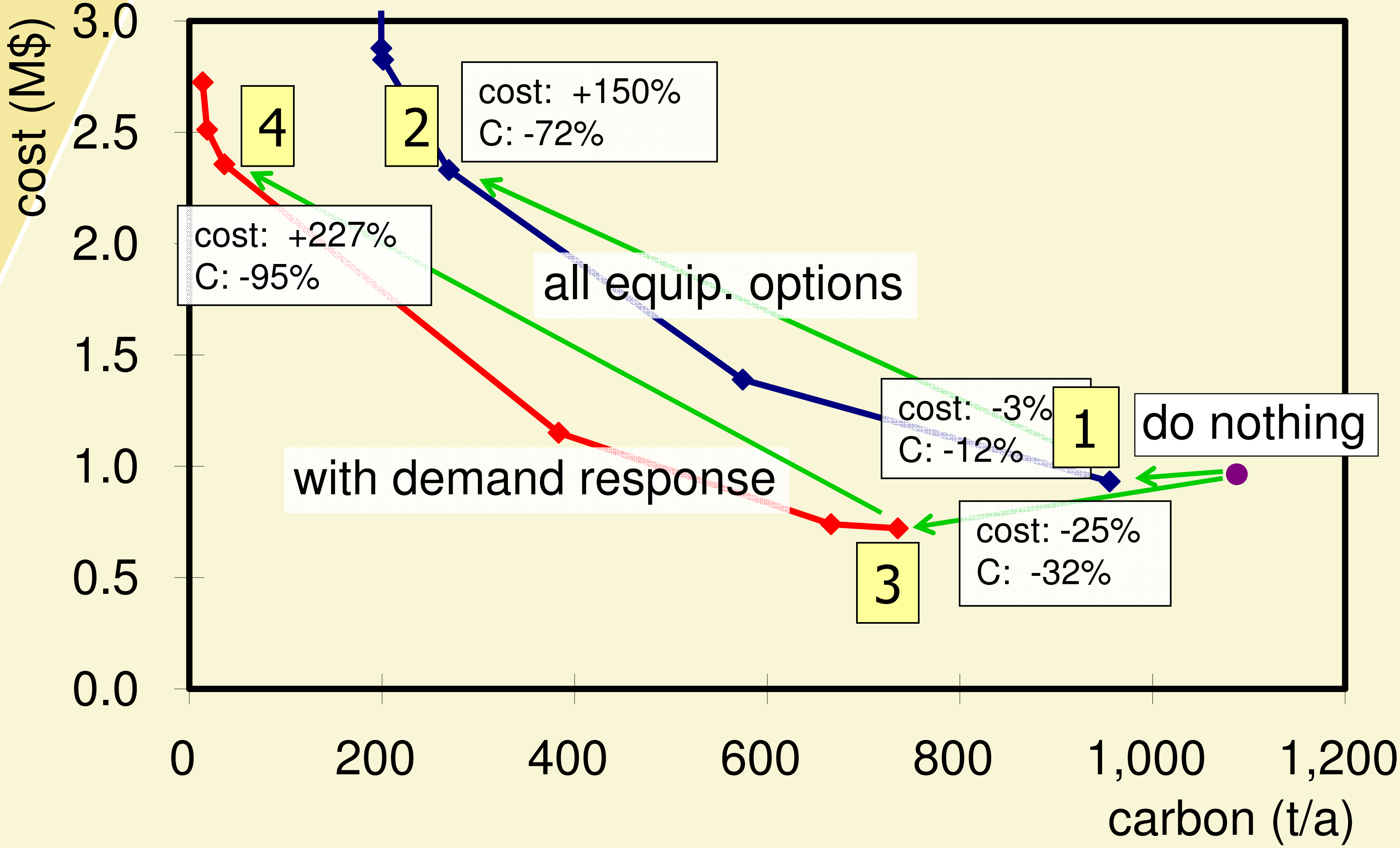
- strategy: cost minimizing
- total energy bill: +85% (increased compared to do-nothing)
- annual carbon emissions: -66% (compared to do-nothing)
- installed equipment:
  - 9897 kWh of heat storage
  - 238 kW of abs. chiller
  - 2408 kW of PV
  - 3952 kW of solar thermal
  - electricity sales = electricity purchase
  - used area constraint = 30 000 m^2 (total building floorspace)

Energy Balances





CA Nursing Home Multi-Objective Frontier



CA Nursing Home Multi-Objective Solution 1

- strategy: cost minimizing
- total energy bill: -3% (compared to do-nothing)
- annual carbon emissions: -12% (compared to do-nothing)
- installed equipment:
  - 300 kWh of CHP (3 ✕ 100 kW Tecogen gensets)

CA Nursing Home Multi-Objective Solution 2

- strategy: 60% of cost and 40% of carbon minimization
- total energy bill: +150% (increased compared to cost minimizing)
- annual carbon emissions: -72% (compared to cost minimizing)
- installed equipment:
  - 19689 kWh of heat storage
  - 250 kW absorption chiller
  - 2148 kW of PV
  - 5309 kW of solar thermal
  - 8843 kWh of electricity storage

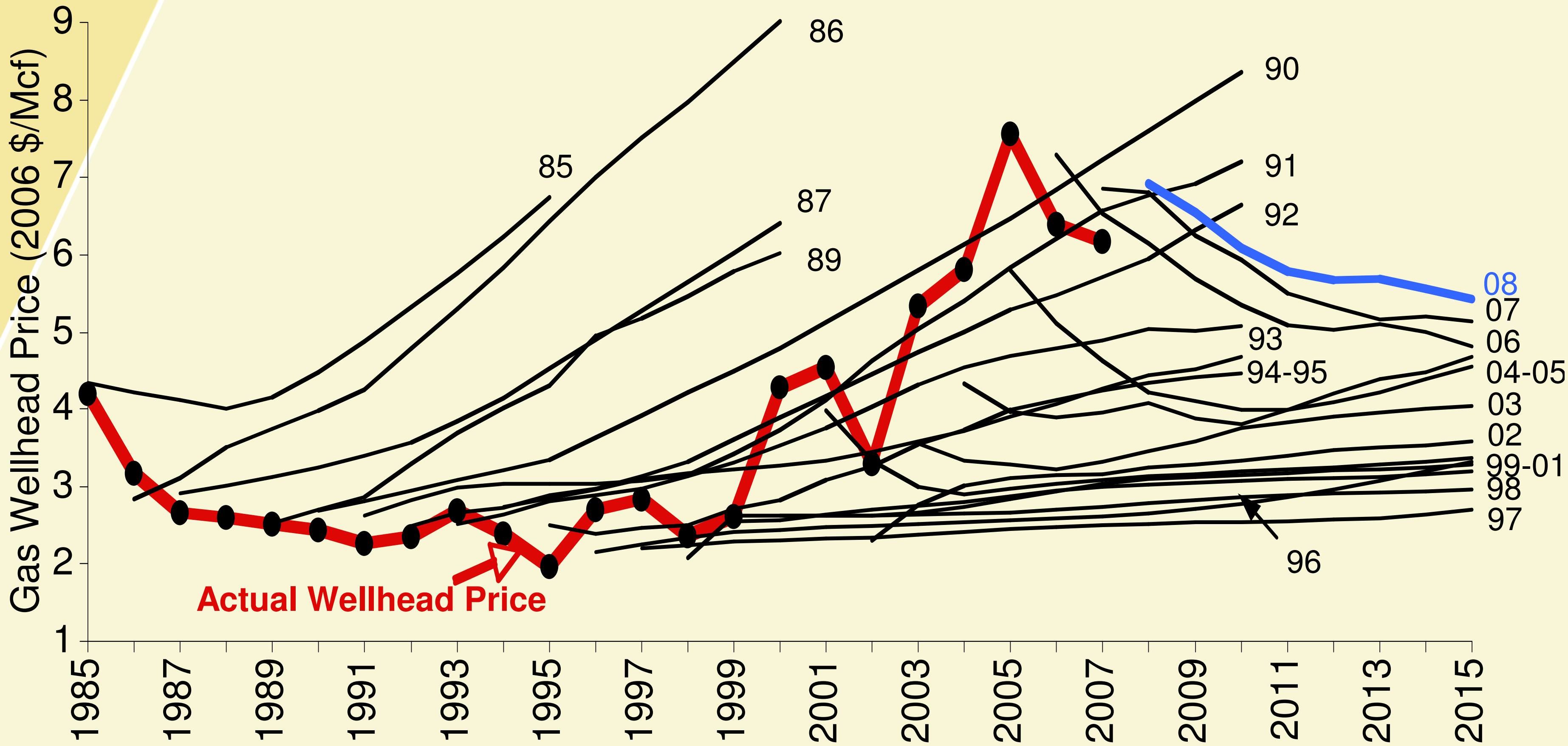
CA Nursing Home Multi-Objective Solution 3

- strategy: cost minimizing + demand response
- total energy bill: -25% (compared to do-nothing)
- annual carbon emissions: -32% (compared to do-nothing)
- installed equipment:
  - 300 kWh of CHP (3 × 100 kW Tecogen gensets)
  - demand response

CA Nursing Home Multi-Objective Solution 4

- strategy: 40% of cost and 60% of carbon minimization
- total energy bill: +227% (increased compared to cost minimizing + demand response)
- annual carbon emissions: -95% (compared to cost minimizing + demand response)
- installed equipment:
  - 15225 kWh of heat storage
  - 207 kW of absorption chiller
  - 2423 kW of PV
  - 4255 kW of solar thermal
  - 11036 kWh of electric storage
  - demand response

Forecast of NG Price



SEDS Objectives

build US energy forecasting model with:

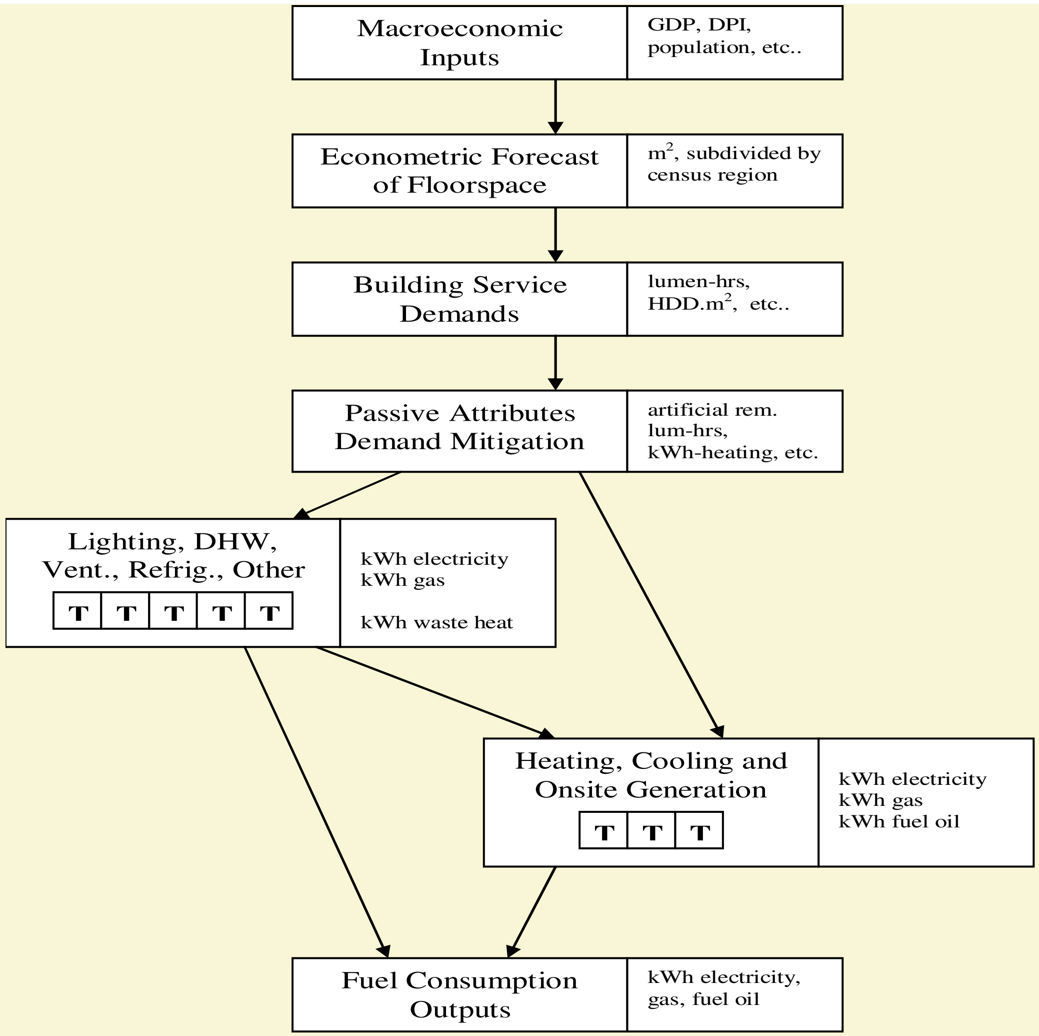
- uncertainty, vision, simplicity, & transparency,
  - > uncertainty: build model on Analytica® platform
  - > vision: 2050 horizon, dramatic tech. & taste change
  - > simplicity: no equilibria or optimization (no iteration,)
  - > transparency: open source, consistent module format
- extremes of policy and outcomes needed
- enough prepackaged technical & budget detail
- ability to run in minutes

Buildings Lite Module

Berkeley Lab responsible for the buildings sector:

- covers both residential and commercial
- tracks building stock
- enables analysis of major buildings R&D programs
- uses expert elicitation of potential advances
- runs stand-alone or integrated
- applies systemic approach

Module Logic Flow

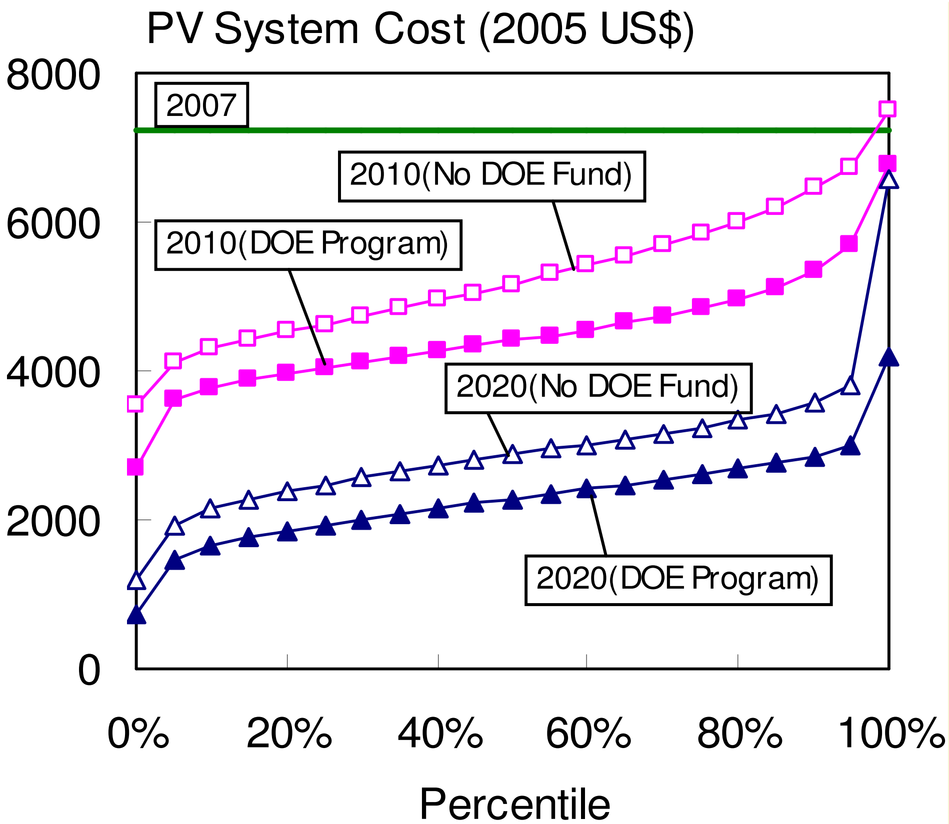


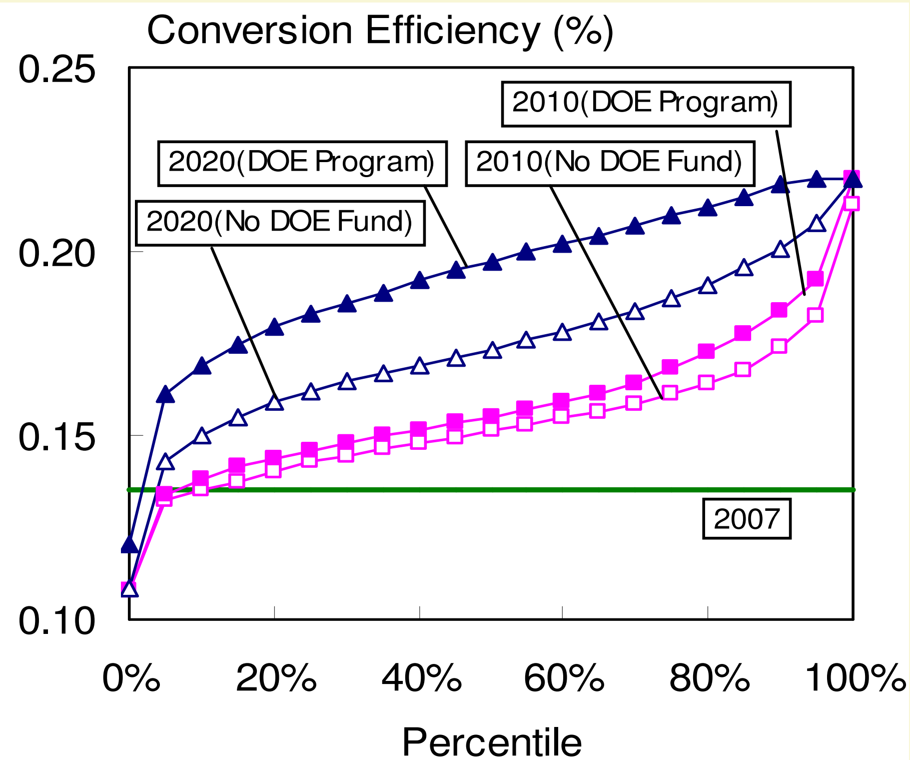
Two Program Examples

first cut photovoltaic and solid state lighting examples:

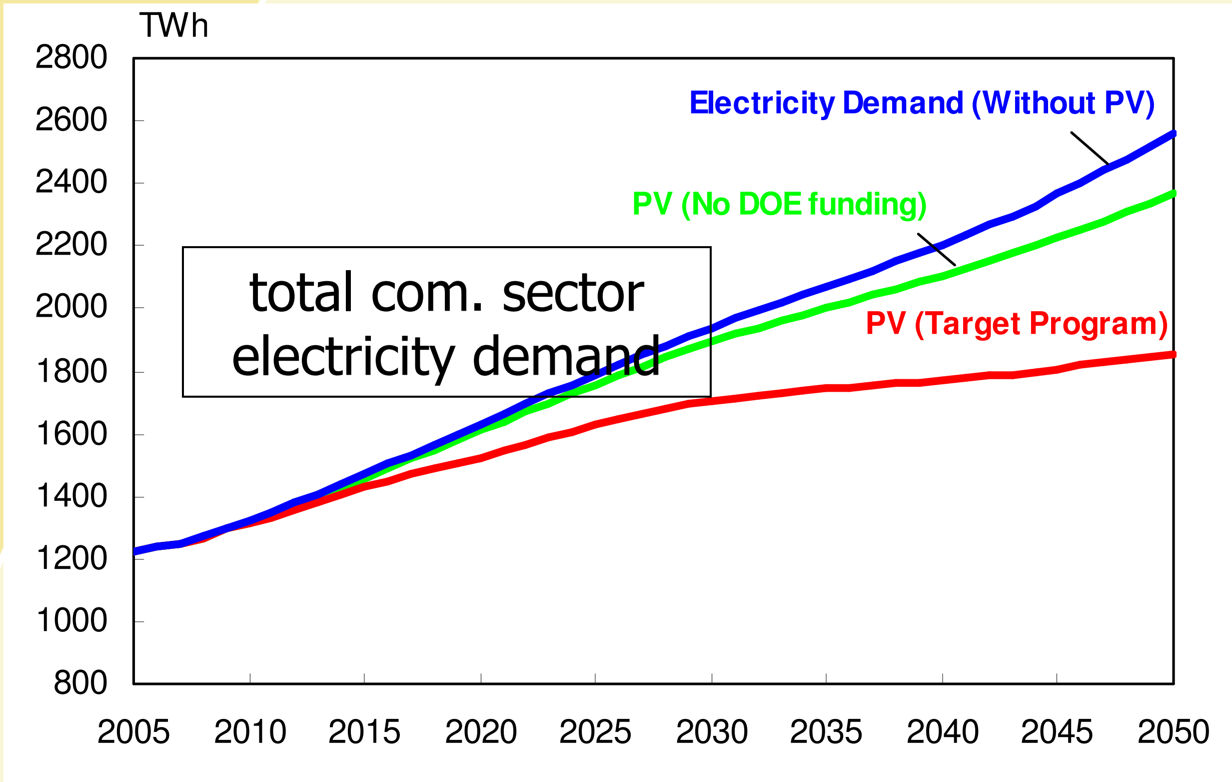
- uses stand-alone SEDS Buildings Lite Module (SBLM) for a ~30-draw Monte Carlo analysis
- takes stochastic inputs for GDP, energy prices, & population
- applies PV/SSL performance forecast based on expert assessment
- implements expert elicitation of potential advances
- employs the systemic approach

Expert Forecasts

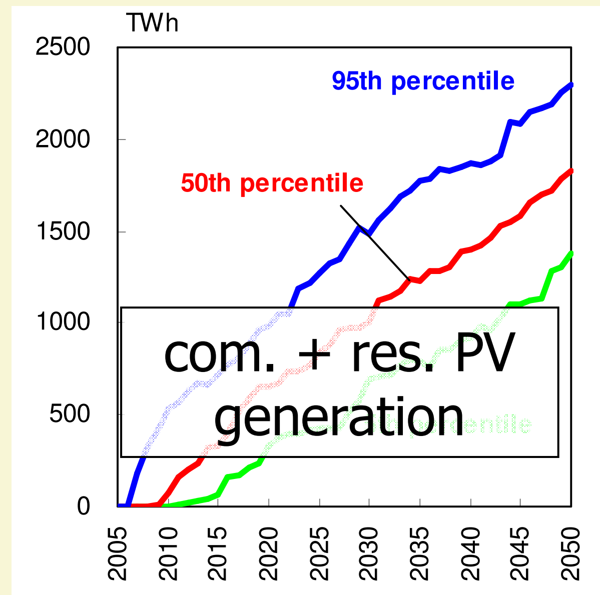




Effect on Demand



total 2050 buildings electricity from PV
without DOE program: 11.7%
with DOE program: 26.1%

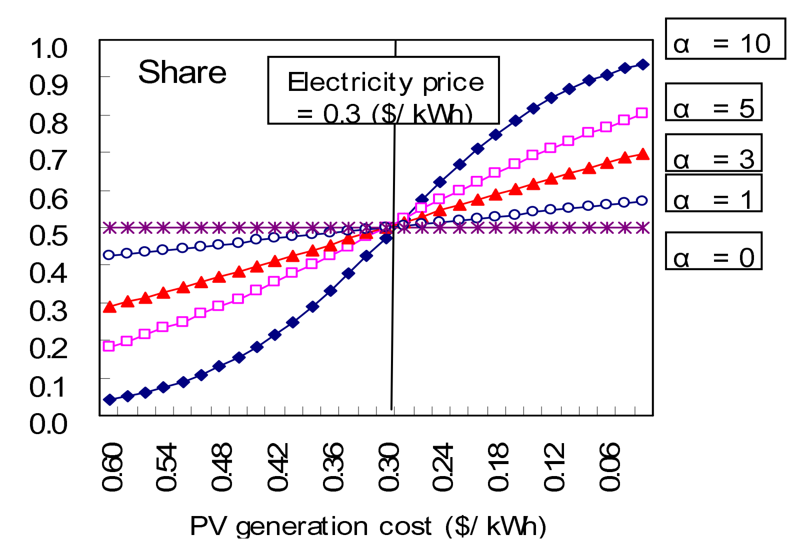


Role of Logit Alpha

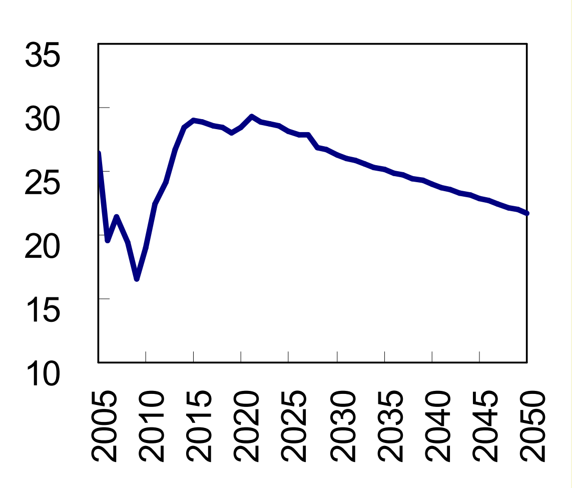
$$MS_{i,t} = \frac{\upsilon_{i,t}}{\sum_i \upsilon_{i,t}}$$

$$\upsilon_{i,t} = \exp(-\alpha * LCOE_{i,t})$$

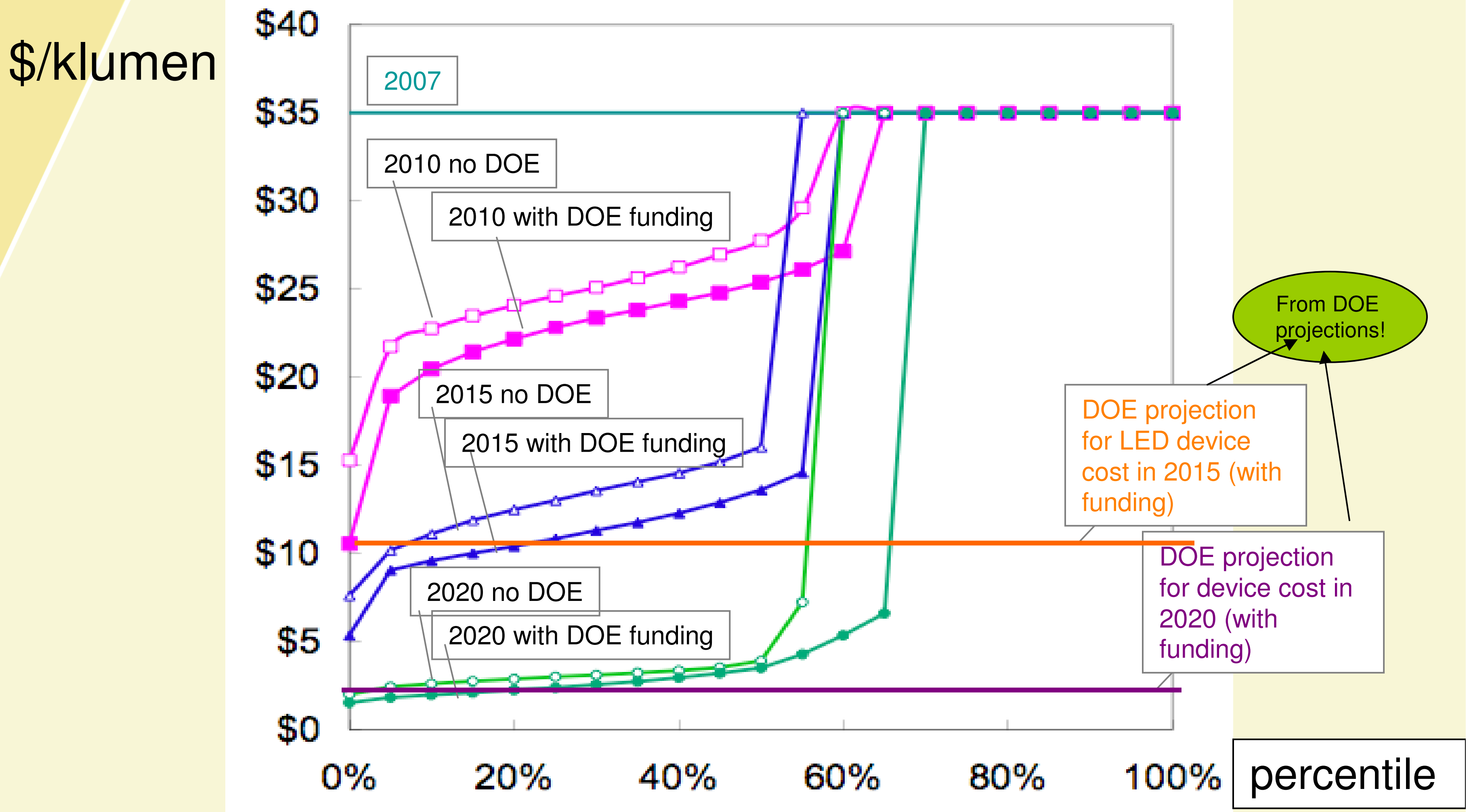
MS = Market share
LCOE = levelized cost of energy (>0)
υ = utility
α = scaling factor
i = technology types
   $i \in$ {utility electricity, PV gen.}
t = time



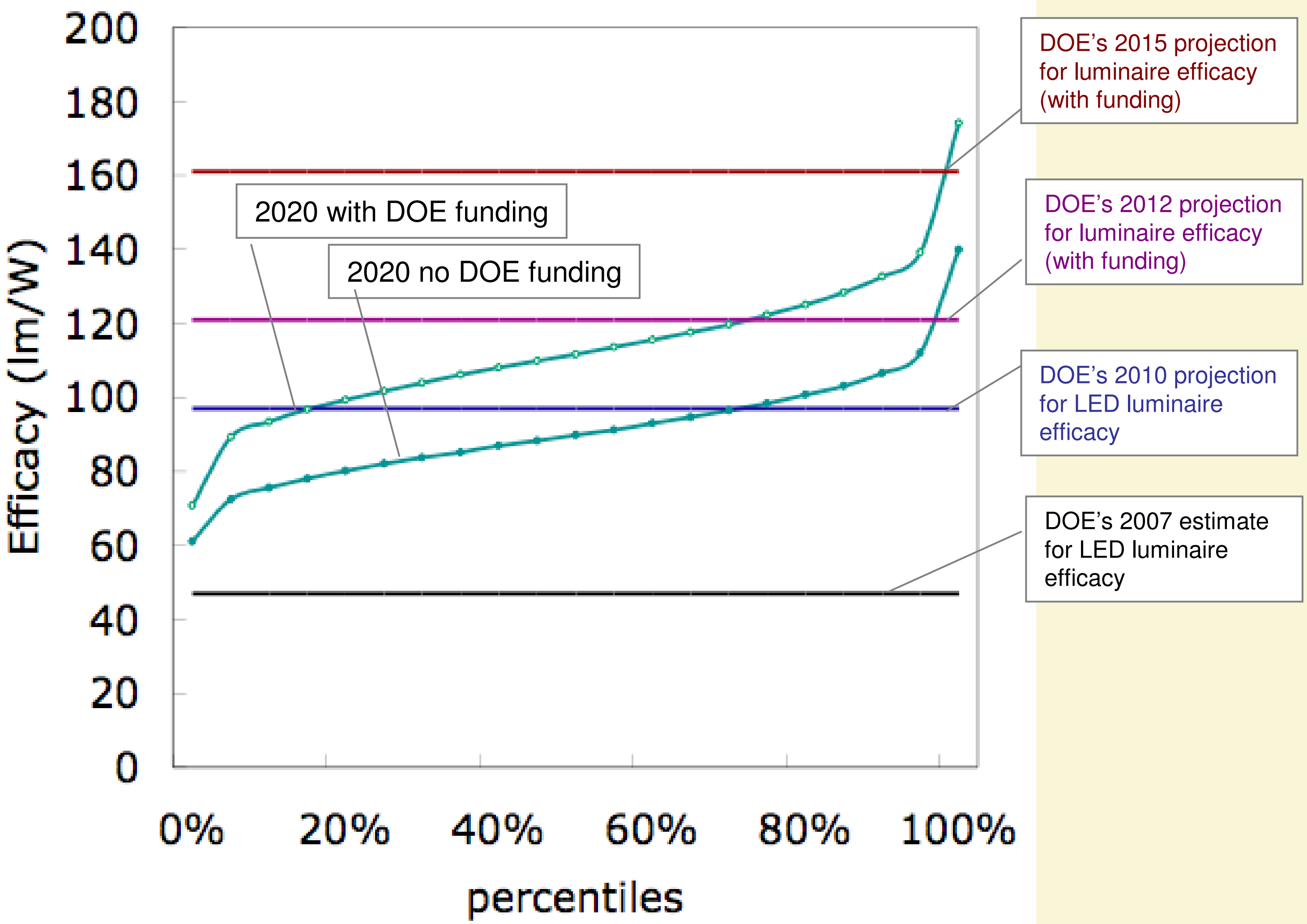
$$\alpha = A + B * electricity \quad price$$



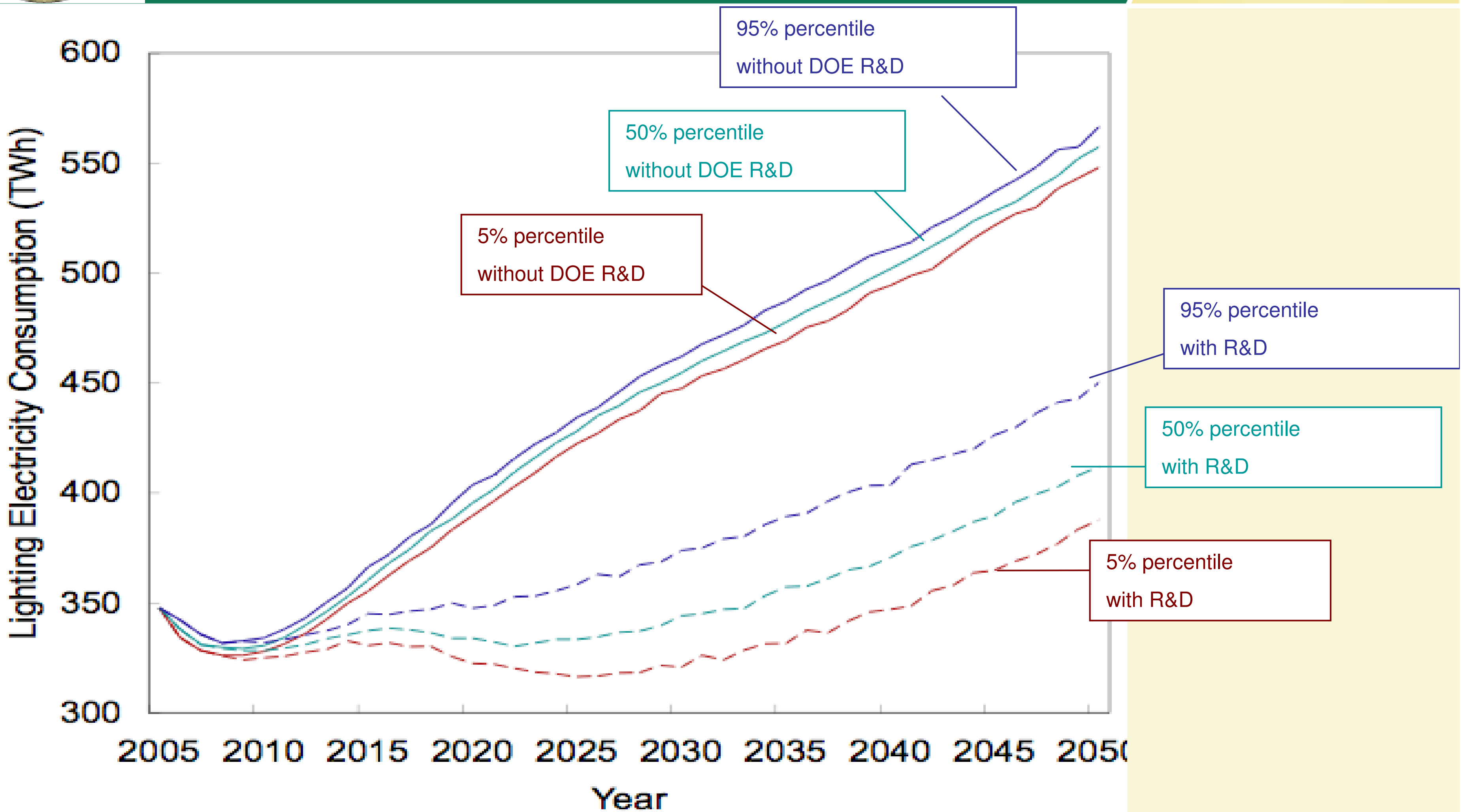
S.S. Lighting Example



SSL Efficacy



Lighting Consumption



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(all papers available at: http://eetd.lbl.gov/ea/emp/ or1 http://der.lbl.gov)

Future Work

systemic approach applied in two distinct models:

- Distributed Energy Resources Customer Adoption Model
- ready for prime time? rewrite, distribution, …
- passive and demand-side measures, better boxes
- forecasting, financials, uncertainty, thermodynamics, mobile sources,
- open source data base of tariffs, equip. perform., etc.
- advanced financial methods, options, sequencing, …
- related studies: ZNEB (less silly), V2M, standard blgs.,

- Stochastic Energy Deployment System
- extend to heavy Module (regions), …, integration, etc.
- windows, & ..